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REPORT NO T7-88

THE EFFECT OF HEAT AND CHEMICAL PROTECTIVE CLOTHING ON THE ABILITY OF A GROUP OF FEMALE SOLDIERS TO SUSTAIN PERFORMANCE OF MILITARY COGNITIVE TASKS

U S ARMY RESEARCH INSTITUTE OF ENVIRONMENTAL MEDICINE

Natick, Massachusetts

DECEMBER 1987

UNITED STATES ARMY
MEDICAL RESEARCH & DEVELOPMENT COMMAND

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SECURITY CLASSIFICATION OF THIS PAGE

AD-A192 596

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1a. REPORT SECURITY CLASSIFICATION Unclassified	1b. RESTRICTIVE MARKINGS None
2a. SECURITY CLASSIFICATION AUTHORITY	3. DISTRIBUTION/AVAILABILITY OF REPORT Approved for public release; distribution is unlimited
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE	
4. PERFORMING ORGANIZATION REPORT NUMBER(S) T7-88	5. MONITORING ORGANIZATION REPORT NUMBER(S)
6a. NAME OF PERFORMING ORGANIZATION US Army Research Institute of Environmental Medicine; 6b. OFFICE SYMBOL (If applicable) SGRD-UE-HP	7a. NAME OF MONITORING ORGANIZATION US Army Medical Research Development Command
6c. ADDRESS (City, State, and ZIP Code) Natick, MA 01760-5007	7b. ADDRESS (City, State, and ZIP Code) Ft. Detrick, MD 21701-5012
8a. NAME OF FUNDING/SPONSORING ORGANIZATION; 8b. OFFICE SYMBOL (If applicable)	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
8c. ADDRESS (City, State, and ZIP Code)	10. SOURCE OF FUNDING NUMBERS

PROGRAM ELEMENT NO.	PROJECT NO.	TASK NO.	WORK UNIT ACCESSION NO.
61102A	3M1611-02BS15	CA	

11. TITLE (Include Security Classification)
The Effect of Heat and Chemical Protective Clothing on the Ability of a Group of Female Soldiers to Sustain Performance of Military Cognitive Tasks

12. PERSONAL AUTHOR(S)
Bernard J. Fine

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15. PAGE COUNT
Final	FROM ____ TO ____	1987, December	32

16. SUPPLEMENTARY NOTATION

17. COSATI CODES		
FIELD	GROUP	SUB-GROUP

18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
Chemical protective clothing, heat, performance, MOPP gear, cognition, stress, fire direction center, chemical warfare, military, mental work

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

We previously have found that chemical protective clothing seriously degraded the performance of sedentary male soldiers doing sustained mental work in the heat. Here in an identical study, we examine the performance of female soldiers in protective clothing. To our knowledge, this is the only controlled study of its kind with women.

Eighteen female soldiers trained for two weeks on cognitive tasks resembling those performed by fire direction center, forward observer and communications personnel. Then, they performed the tasks for seven-hour periods on four successive days in hot (91°F., 61% RH) and normal (55°F., 35% RH or 70°F., 35% RH) conditions, with and without chemical protective clothing.

(Continued)

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT ☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT ☐ DTIC USERS	21. ABSTRACT SECURITY CLASSIFICATION Unclassified
22a. NAME OF RESPONSIBLE INDIVIDUAL Bernard J. Fine	22b. TELEPHONE (Include Area Code) 617 - 651-4855; 22c. OFFICE SYMBOL SGRD-UE-HP

DD Form 1473, JUN 86 Previous editions are obsolete. SECURITY CLASSIFICATION OF THIS PAGE

UNCLASSIFIED

19. ABSTRACT (continued)

SUMMARY AND CONCLUSIONS: The data indicate that after three hours in the hot environment, while clad in MOP IV, the women, as a group, showed a marked decrease in the ability to sustain performance. Of the seventeen soldiers tested, two had to be evacuated from the heat in the third hour of exposure, three in the fourth and five in the fifth. The remaining seven participants showed no adverse effects of heat and MOPP IV on the performance of any task. No differences were found between heat casualties and non-casualties in core temperatures or in water consumed during the heat exposure. Reasons for evacuation included fainting, about to faint, incoherent responses to questions, feelings of total exhaustion, or an expressed statement by the participant that she wished to terminate.

In terms of unit performance, the necessary evacuation of more than 50% of the "unit" represented by the women in this study, prior to six hours of heat exposure, has serious implications. Additional research is needed to determine whether gender differences observed between this and a previous study with male soldiers reflect basic physical, physiological or psychological differences between sexes or reside in transient factors peculiar to the specific samples involved, such as differences in physical fitness, size, attitude or experience.

The performance of a majority of the participants also was adversely affected by wearing MOPP IV at 55°F., despite having had eight hours of practice on the tasks in the gear at that temperature. This result is similar to, but more severe than, that found with male soldiers. Reasons for the adverse affect are unclear, but do not seem to be due to interference of gloves and/or mask with dexterity or vision. The stress of adapting to the novel experimental situation for the first time is posited as a possible explanation. Training personnel to do their jobs in MOPP IV under the most realistic conditions possible is recommended.

1. The views, opinions, and/or findings contained in this report are those of the author(s) and should not be construed as an official Department of the Army position, policy, or decision, unless so designated by other official documentation.

2. Human subjects participated in these studies after giving their free and informed voluntary consent. Investigators adhered to AR 70-25 and USAMRDC Regulation 70-25 on Use of Volunteers in Research.

ACKNOWLEDGEMENTS

Ms. Edith A. Crohn was indispensible in all phases of the research; from readying materials and equipment, to testing, monitoring and interacting positively with the participants, to tabulating and scoring the data, she always provided ready and cheerful support.

Specialist 4 Linda S. Gowenlock ably assisted in various phases of testing and monitoring the participants and in providing logistical support.

Major Anne E. Allan, the Medical Officer assigned to the study, was exemplary in her close and caring monitoring of all of the participants during the stressful aspects of the research.

Sgt. Anthony D. Marshall provided helpful logistical support.

Drs. Lou A. Stephenson and Margaret A. Kolka were especially helpful in providing information about female physiology and thermoregulation as related to performance in the heat.

To all, my deepest appreciation.

Special thanks to the women who volunteered for and participated in the project. Their depth of committment to sustained mental work is evidenced by the control values obtained in the study.

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TECHNICAL REPORT

NO. T7-88

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BERNARD J. FINE, PH.D.

December 1987

Health and Performance Division

US ARMY RESEARCH INSTITUTE OF ENVIRONMENTAL MEDICINE
NATICK, MASSACHUSETTS 01760

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SUMMARY AND CONCLUSIONS: The data indicate that after three hours in the hot environment, while clad in MOPP IV, the women, as a group, showed a marked decrease in the ability to sustain performance. Of the seventeen soldiers tested, two had to be evacuated from the heat in the third hour of exposure, three in the fourth and five in the fifth. The remaining seven participants showed no adverse effects of heat and MOPP IV on the performance of any task. No differences were found between heat casualties and non-casualties in core temperatures or in water consumed during the heat exposure. Reasons for evacuation included fainting, about to faint, incoherent responses to questions, feelings of total exhaustion, or an expressed statement by the participant that she wished to terminate.

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The Effect of Heat and Chemical Protective Clothing on the Ability of a Group of Female Soldiers to Sustain Performance of Military Cognitive Tasks

Bernard J. Fine

U.S. Army Research Institute of Environmental Medicine, Natick, MA

The clothing currently worn by military personnel for protection against chemical agents is relatively impermeable and severely limits the dissipation of heat from within. This creates a debilitating and potentially hazardous micro-environment for the wearer.

Serious limitations on the ability to perform physical activities in the heat or even in temperate climates while clad in chemical protective clothing have been shown in a number of studies (e.g. 9,10,11). Likewise, the ability to perform mental work in temperate and moderately hot environments while in the protective clothing has been found to be impaired (5,13,14).

Of particular interest here, Fine & Kobrick (5) found a marked deterioration of the mental performances of a number of highly trained soldiers after four to five hours in the heat (91°F.,60%RH), while wearing protective clothing. By the end of seven hours, they found increases in percent group error on investigator-paced tasks ranging from 17-23% over control conditions. The productivity of the group on a self-paced task diminished by approximately 40% from control conditions after six hours in the heat, but accuracy did not appear to be affected.

These limitations on mental performance are sufficiently severe to merit their being considered in many aspects of logistical and tactical planning, particularly for operations in warmer climates.

As far as can be determined, all of the available information on sustained cognitive performance in the heat while wearing chemical protective clothing has been obtained from males; we know of no research in this area on women. While they are not permitted in the combat arms, significant numbers of women, in occupations requiring sustained cognitive activity, are in support units which, undoubtedly, will be required to perform in scenarios in which chemical agents may be present.

There is no real basis upon which to predict differential cognitive performance of women relative to that of men under conditions of heat stress and protective clothing. As noted by Stephenson and Kolka (15), there have been few thermoregulatory differences shown between men and women in studies appropriately controlled for factors (e.g., physical fitness) which independently affect thermoregulation. While there is some evidence that women's cognitive performance is related to their menstrual cycles (3), and that thermoregulation varies with phase of menstrual cycle (15), there appears to be no evidence relating thermoregulation to cognitive performance.

To help alleviate the lack of information about female performance, we here report the results of a research study which is an exact replication of that done by Fine & Kobrick (5), only with female soldiers as participants.

Fine & Kobrick have noted (5) that a major requirement of military stress research should be that it be performed in the context of a realistic military scenario, so as to satisfy the following criteria:

a. participants should perform tasks that would be performed routinely by some troops during a chemical attack;

b. tasks should be overlearned, as they would be among highly trained troops;

c. exposure to stress should be at least as long as the period of time for which the protective ensemble is considered to provide effective physical protection.

To satisfy these criteria, they used a set of performance tasks that they had used successfully in previous research (6,7,8). The tasks were similar to some of those performed by members of Artillery Fire Direction Center (FDC) teams, by forward observers and by Army communications personnel. These are among the most important tasks of those required during chemical attacks, since effective artillery operations and efficient and accurate communications will be essential for defense of troops that have been immobilized by chemical agents.

It is important to note here that some of the tasks used are similar to those performed in the combat arms and that females usually will not be expected to perform them. However, these tasks reflect basic mental processes such as arithmetic reasoning, decoding, etc., which give them a high degree of generalizability.

Method

Subjects

Eighteen female soldier volunteers, ages 20-34 (median=22), were studied. All had been examined by a medical officer to insure that they were in good health. Only personnel able to read without glasses or who had corrective lens inserts for the protective mask were acceptable.

All participants were briefed on the purposes, design and potential hazards of the study and signed consent forms. The research conformed to AR 70-25 and USAMRDC Regulation 70-25 on Use of Volunteers in Research.

Tasks

Four tasks were used as the major dependent variables. Each was designed to be consistent with controlled scientific investigation while, at the same time, having credibility as a genuine military activity.

(1) Computation of "Site:" - "Site" is an adjustment used by FDC's to correct for asymmetrical trajectories of artillery rounds. The correction is based on known values for various types of rounds, sizes of charges and target distances, and was computed in this study using a regulation artillery slide rule. (Calculations now are done with computers. However, it is my understanding that slide rules and other "tools" are carried by FDC personnel who are trained to use them in the event of computer failure. BJF) The data necessary to compute site were pre-recorded and transmitted to the volunteers through headphones. A format similar to that for communicating artillery fire missions was used. Participants were required to enter incoming information on a form, perform arithmetic calculations, set data into and read answers from a fairly complex slide rule, and record their anwers, with appropriate algebraic signs.

(2) Receiving and decoding map grid coordinates using a decoding device ("codewheel"): - Tape-recorded map grid coordinates were transmitted in alphabetic code through headphones in the format of typical military messages. Participants had to record the coded messages on a special form, select the appropriate one of three codewheels, transcribe the coded material into a numeric format and record the transcription on the form.

(3) Receiving and decoding messages using a simulated Army codebook: Pre-recorded, coded messages, varying in length from five to eight words, were transmitted to the participants in the same format as official military messages. They had to record each message on an appropriate form, decode the message by referring to the codebook and record the translation on the form.

(4) Plotting targets and determining ranges and deflections: - All participants were issued identical maps (scale 1:25,000) on which three artillery battery positions had been pre-plotted along with deflection reference points. They also were given identical lists of targets to plot. Each participant was required to plot each target using a regulation artillery plotting scale, mark the location of the target by inserting a map pin in the appropriate spot, draw a circle around the target and write the target number in the circle. Next, they determined the range and deflection of the target from a designated battery using an artillery protractor. Finally, they recorded their answers on a form and included the time of completion of the calculations for each target. This enabled quantification of number of targets plotted per unit of time.

Further complications were introduced by having a number of "No Fire Zones," delineated by sets of grid coordinates, listed on each person's report form. Participants had to signal their awareness of these zones by indicating on the form whether or not they should fire at each target they plotted. The zones were changed after every ten targets to prevent their memorization and to increase the need for constant awareness.

The Site computation, codewheel and codebook tasks, referred to as "radio-transmitted" tasks, were paced by the rate at which the radio messages were sent and could not be controlled by the participants. The map plotting task at times was paced by study design requirements (see

Design and Procedure section) and at other times was "self-paced," that is, each participant had control of her own work rate.

The participants did not know which of the three radio-transmitted tasks they would be required to perform until a specific message arrived.

The messages were realistic in content and form and realism was enhanced by the use of a variety of voices and levels of background noise.

More details about and examples of these tasks are available in the appendices of Fine & Kobrick (5).

In addition to the above tasks, a number of tests and measures were administered at various times during the study. These included eye-hand coordination measurement using a video-game air combat task, selected perceptual measures including acuity, color discrimination ability and contrast sensitivity, a number of questionnaires related to personality measurement, personal preferences and habits and demographic information and some paper-and-pencil tests which were felt to be possible predictors of mental performance under stress. Results from these measures will be reported elsewhere. All tasks and tests were fully described to the participants before they volunteered.

Design and Procedure

The participants were scheduled to arrive at three-week intervals in six-person groups. Four groups (24 persons) were expected over a period of approximately four months. Because of long-range scheduling problems and difficulties in obtaining volunteers, five groups, varying in size from three to four members (18 persons), were obtained over a period of six months, at which time it was decided to terminate the study. Each group completed its assignment before the next group arrived.

Each group underwent two weeks of intensive training followed by one "experimental" week, the purpose of which was to evaluate performance in the heat while wearing the protective clothing. Training took place in an environmentally-controlled dressing room temporarily converted to a classroom. The "experimental" week of testing took place in a large climatically-controlled chamber.

The configuration of protective clothing worn is known as MOPP IV (Mission Oriented Protective Posture; configuration IV refers to total encapsulation. This includes the suit, worn completely closed over the battle dress uniform, along with boots, gloves, mask and hood.)

All participants were briefed at length to set the tone for the study. They were told that they would be performing a number of tasks similar to those performed by some members of FDC teams, forward observers and communications personnel. Emphasis was placed on the importance to Army planning of the information generated by the study. More details concerning the briefing and the contents of the volunteer agreement can be found in Fine & Kobrick (5).

In the two-week training period, participants practiced six to seven hours per day, exclusive of week-ends. Training on the site computation, codewheel and codebook tasks was designed to be a gradual process, beginning with a simple written format and progressing through oral presentations by the instructor, slow radio transmissions using the instructor's voice, slow radio transmissions with a variety of voices and, finally, at normal speed, with a variety of voices.

During the training period, participants practiced several hundred radio messages with immediate feedback of correctness of response and discussion of possible reasons for errors. Continued emphasis was placed primarily on accuracy and secondarily on speed

Training on the map task involved plotting hundreds of targets with accompanying range and deflection determinations over the two-week period, with immediate feedback of the correctness of responses. Again, accuracy was continually and emphatically stressed. Only after participants had demonstrated their ability to perform accurately were they encouraged to increase the speed of their work.

For all tasks, each participant was given individual attention, particularly during early stages of training and when new procedures were introduced.

During the first week, participants were gradually introduced to performing with critical components of the protective clothing, i.e. gloves and/or mask. During the second week, they performed the tasks daily in the morning with and in the afternoon without the full MOPP IV configuration at the appropriate ambient temperatures (see below).

By the beginning of the experimental week, everyone had performed all tasks in MOPP IV for about eight hours, spread over five days.

The schedule for the "experimental" week was as follows:

Monday: -A one-hour "refresher" run to bring participants back to pre-weekend performance levels;

Tuesday: -Control Day, seven hours at 70°F., 35% RH, battle dress uniform (BDU); referred to as "BDU-Control-1;"

Wednesday: -MOPP Control Day, seven hours at 55°F., 35% RH, MOPP IV worn over BDU; referred to as "MOPP-Control;"

Thursday: -Control Day, same as Tuesday; referred to as "BDU-Control-2;"

Friday: -Heat Stress Day, seven hours at 91°F., 61% RH, MOPP IV worn over BDU; referred to as "MOPP-Heat-Stress."

The "MOPP-Control" day was kept at 55°F. because encapsulation in the suit could cause a heat load for the participants, even at moderate temperatures. The 55°F. temperature in MOPP IV was calculated by Breckenridge (2) as equivalent to the 70°F. condition in BDU for a seven-hour exposure.

With regard to the environmental conditions, Fine & Kobrick (5) have noted that:

> "The environmental conditions used on the Heat Stress Day are the same as those used to evaluate physiological performance in the M1E1 tank (22). They approximate conditions that should occur about 1% of the time during the summer in central Europe and they are considerably lower than conditions which would be encountered in areas of the Near East. For example, mean maximum temperatures for May, June, July, August and September in Jalalabad, Afghanistan exceed 100 degrees F. (dry bulb) with mean humidities ranging from 45% in May and June to 71% in September. In Abadan, Iran, mean daily maximum temperatures in July and August are approximately 110°F. (dry bulb) with a mean humidity of 52% (6)."

The radio-transmitted tasks were presented as one-hour blocks of messages. The content of the messages and the interval between messages varied according to a pre-determined random pattern. Intervals between messages ranged from approximately 30 seconds to over two minutes. No two messages were the same over the four days of the experiment.

Twenty-five messages were transmitted to each participant per hour. Five of the messages were irrelevant, i.e., messages with addresses to which the participants had been trained not to respond. Of the remaining messages, six were for the codewheel, six for the codebook and eight for computation of Site.

All participants received identical messages each hour. The order in which the messages were transmitted, that is, whether a message was a Site computation, codewheel or codebook message, or was irrelevant, was pre-established and kept constant for all hours for each person. However, th order varied from person to person, i.e., participant #1 received a sequence of messages from #1 to #25 , and had the same sequence for all hours in which she received messages. Participant #2 received the identical messages, but her sequence started with message #2 and ended with message #1. Participant #3 started with message #3 and ended with message #2 and so on. This procedure insured that everyone was not working on the same message simultaneously, and effectively prevented the copying of answers and the alerting of inattentive people to the fact that a message was being transmitted.

Each hour in which messages were presented was matched as to the form of the message. That is, if message #3 was a codebook message in hour #1, not only was it a codebook message in all other hours, but it also contained the same number of words to decode. Similarly, if message #7 was a Site calculation message, not only was it always a Site calculation message, but it was always of the same level of difficulty.

The radio-transmitted messages were presented to the subjects four times on each of the four experimental days as hours 1,3,5 and 7.

At the same time that they were monitoring and responding to radio messages, participants were required to work on their maps, plotting targets and determining ranges and deflections when not engaged in actual message reception and translation. Thus, for each of hours 1,3,5, and 7, each person was continuously engaged in mental work. During these hours, radio messages were given highest priority and everyone was required to interrupt their map work immediately upon hearing a radio transmission. Upon completion of what was required of them by the radio message, they then returned to the map task and resumed working.

During hours 2,4 and 6, all participants worked continuously on map plotting and were interrupted twice for brief individual testing of contrast sensitivity and eye-hand coordination. During these hours, all participants worked at their own pace on the map task for at least 30 continuous minutes without interruption.

Each "one-hour" period included a ten-minute rest break.

Safety Precautions

As a precaution on the Heat-Stress-Day, rectal temperatures were monitored at five-minute intervals (more frequently if temperatures approached 102°F.). Removal from the heat was required if core temperature reached 103°F.

Since facial expressions could not be seen through the face masks, participants were closely monitored and periodically questionned about their well-being during the heat exposure. Each person had a canteen of cool water available and was continuously reminded to drink, particularly during rest periods. Water intake was closely monitored to insure that subjects were complying.

Because it was impossible to eat while wearing the mask, a mid-day meal was not permitted on any of the experimental days, in order to keep conditions constant; participants volunteered knowing of this restriction.

Smoking was not permitted during training except during breaks, and was not permitted at any time during testing hours of the experimental week. During the experimental week, access to a portable toilet was permitted, but was discouraged; very few subjects availed themselves of the toilet. Since no doctrine appears to exist with respect to the waste disposal problem, it was considered impractical in this study to prevent subjects from relieving themselves.

Results

The data of one participant were excluded from analysis; her performance during training and experimentation was very atypical. All data analyses are based on N=17.

The participants' responses to the radio messages were scored for accuracy using the same criteria as Fine & Kobrick (5,Appendix 6). Each person's responses were rated independently by two scorers. The scorers' responses were then compared and discrepancies were resolved by consulting the original data and discussing the differences. Rather than reflecting differences in interpretation, differences between scorers typically were found to reflect an error on the part of one of the scorers.

Errors were classified into those of omission and commission. An omission error involved missing part of an incoming message or performing an incomplete translation of it. Errors of commission involved recording incoming information erroneously or erring in computing or translating it.

In the MOPP-Heat-Stress condition, ten participants were evacuated for medical reasons; two in the third, three in the fourth and five in the fifth hours. No one was removed because of hyperthermia. (Average rectal temperature at time of removal for ten persons was 100.8° F; only one person reached 102.2°F. Average temperture for seven people who stayed in was 100.4° F. for each of hours five and seven. No differences in water consumption were found between those who stayed in and those who became casualties. Body weights were not obtained, so weight loss could not be ascertained.) All evacuees had either fainted, indicated that they were about to faint or were judged to be incapable of continuing by the medical officer and/or principal investigator. Various criteria entered into judgments to remove someone, including: dizziness, incoherent responses to questions, feelings of total exhaustion, cessation of performance, or an expressed statement by the participant that she wished to terminate.

As an index of the performance of the entire group, and for purposes of comparison with Fine & Kobrick (5), their scoring system was used. Evacuees were given the maximum number of omission errors possible for the radio messages and scored as having plotted no targets for the time period they missed. Group averages reported for all tasks reflect this method. This provides a more realistic assessment of unit performance than would the exclusion of the data of persons no longer in the situation. Thus, the results should be interpreted as indicating the relative ability of the entire original group of 17 persons to sustain performance over the seven-hour period. The method used here provides a "worst case" analysis; heavy weight is placed on becoming a casualty. This procedure has been discussed by others at various times (See Fine & Kobrick;5, page 121). It is felt to be particularly important where results may contribute to the planning of operations in which the lives of the participants are at stake. Omitting data of evacuees provides a much too optimistic picture of the effects of the stressors on unit performance. In this study, the necessary evacuation of 10 of 17 members of the "unit" for health reasons and the depiction of the results of this evacuation in the accompanying graphs conveys a critical message about operations in MOPP IV in the heat.

With respect to the overall performance of the group, it is important to note that the seven women who were not evacuated showed no significant adverse effects of heat on the performance of any task.

Separate analyses of variance (ANOVA'S) were performed for each of the tasks, based on the individual error scores. The results of these analyses are presented in the text below. They pertain to the main effects of experimental conditions, elapsed hours of work and their interactions.

The number of errors made by each person for each "radio" task was converted to percent of total errors possible for that task. Group averages were calculated from these values and are the basis for the graphs presented below. The graphs also depict the results of tests of significance (Least Significant Difference Test;1,12) for "internal" comparisons (differences between elapsed hours of work within conditions, or between conditions after a certain number of elapsed hours of work).

Capital letters in each graph (e.g.,B,AB,A,A), displayed vertically, refer to the results of tests of significance between CONDITIONS, with elapsed hours of work held constant. Lower case letters (e.g., a,a,b,c), displayed horizontally, refer to the results of tests of significance between ELAPSED HOURS OF WORK within a given condition.

With regard to the tests of significance between conditions (capital letters), the letters always are presented in the same order as the means of the conditions depicted below them on the graph, reading from top to bottom. Differences between any two conditions having NO letters in common are significant ($P < .05$).

For example, see Figure 1a, Hour 1. B,AB,A,A refer to the conditions MOPP-Control, MOPP-Heat-Stress, BDU-Control-1 and BDU-Control-2, in order, reading from the top scaled line to the bottom one. Here, the group mean percent error score in the MOPP-Control condition (B) is significantly different from both BDU-Control-1 (A) and BDU-Control-2 (A), but not from the MOPP-Heat-Stress Condition (AB). The MOPP-Heat-Stress condition (AB) is not significantly different from any other condition since it shares either an A or a B with them. The two BDU-Controls are not significantly different from one another because both have the same letter assigned (A).

With regard to differences between elapsed hours of work within conditions (lower case letters), the order of the letters is always the same as the order of the hours within the condition; that is, the first letter always refers to the first hour of testing for that condition, the second letter refers to the second hour of testing, etc.

For example, in Figure 1a, the results of the tests of significance between hours within the MOPP-Heat-Stress condition (a,a,b,b) indicate that the mean percent group error scores of the first (a) and second (a) hour of testing on this task (actually hours one and three of the experiment; see design section) did not differ significantly from one another, but that both differed significantly ($P < .05$) from the third hour (b) and fourth hour (b) of testing (actual hours five and seven) which, in turn, did not differ f om one another, since both were scored (b).

CODEBOOK: Results for the Codebook task are depicted graphically in Figure 1a for total group mean errors and in Figures 1b and 1c for group mean errors of omission and commission separately.

With regard to total errors, an ANOVA resulted in significant main effects for Conditions (F=40.31; df 3,256; P <.00001) and Elapsed Hours of Work (F= 11.93; df 3,256; P< .00001) and a significant interaction between the two (F= 7.51; df 9,256; P< .00001).

No significant differences between the two BDU-Control conditions were evident at any hour of testing, nor were there any significant differences between hours of testing within either of these Control conditions. This indicates that the participants had reached a very consistent level of performance on this task and that performance of the task under non-stressful conditions was not affected by time on the task. This attests both to a high level of motivation and effective training.

The protective suit, by itself (MOPP-Control condition), appeared to cause a significant decrement in performance of the Codebook task. Comparison of the MOPP-Control condition with each BDU-Control condition yielded significant decrements at all hours of comparison. This result is similar to but somewhat stronger than that obtained by Fine & Kobrick (3) with males. Thus, despite approximately eight hours of familiarization with and practice in MOPP IV during training (at the same 55°F. temperature as in the experiment), performance was poorer in MOPP IV; group average decrements ranging from 25% to nearly 38% over the seven hour period were obtained.

With regard to performance in the heat, no clear cut effects of heat were observed until the fifth hour when highly significant average decrements (57%) occurred. After seven hours, the decrements averaged

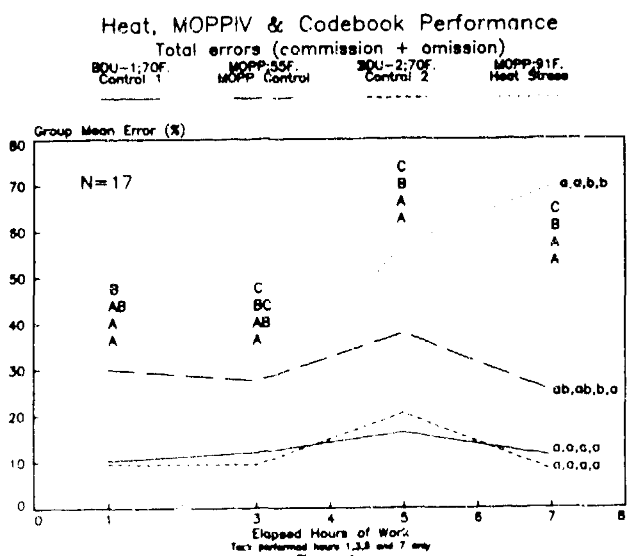

Figure 1a

nearly 70%. (It should be re-emphasized here that the large decrements in the fifth and seventh hours were due to the evacuation of many participants from the chamber as heat casualties.)

As shown in Figures 1b and 1c, the decrements in group performance in both the MOPP-Control and MOPP-Heat-Stress conditions were due primarily to increases in errors of omission, rather than in errors of commission.

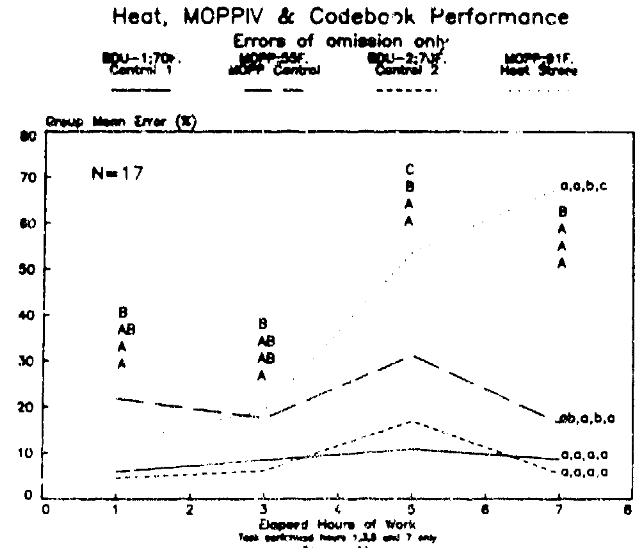

Figure 1b

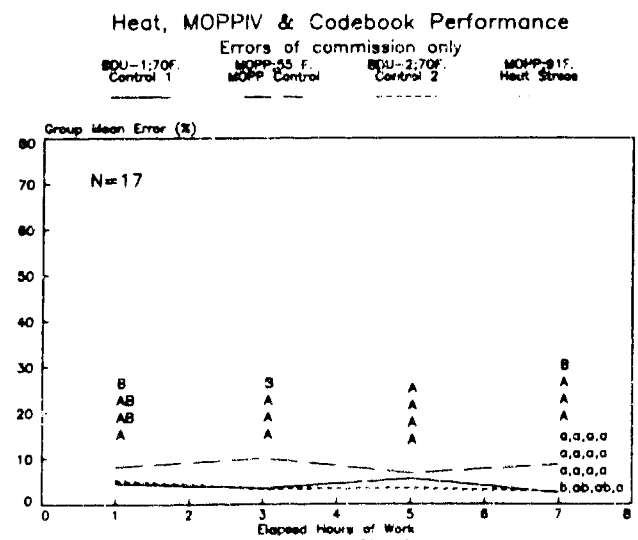

Figure 1c

CODEWHEEL: The results of the Codewheel Task are shown in Figures 2a, 2b and 2c. For total errors (errors of omission plus errors of commission, Figure 2a), an ANOVA yielded a significant main effect for Conditions (F=40.76; df 3,256; P<.00001), a significant effect for Elapsed Hours of Work (F=8.41; df 3,256;P<.00001) and a significant interaction between the two variables (F=7.87; df 9,256; P<.00001).

As was the case with the Codebook task, performance in the BDU control conditions showed remarkable consistency and stability over the seven hour period; no significant differences were observed between the two conditions at any hour or between hours in either condition.

The MOPP-Control condition showed a significant decrement (when compared with both BDU-Control conditions) in the first and third hours.

The MOPP-Heat-Stress condition showed no adverse effect of heat after the first hour. In the third hour, performance in the MOPP-Heat-Stress condition was significantly poorer than in either BDU-Control condition, but was not different from the MOPP-Control condition. Thus, as was the case with the codebook task, for the first three hours, the decrement in performance appears to be attributable to the protective suit per se and not to a suit-heat interaction. The effects of heat became evident by the fifth hour, however, wherein large increases in group percent error were observed. By the end of the seventh hour of exposure, the average group error reached 68.6%. Again, note that these large decrements were caused by the evacuation of people from the chamber.

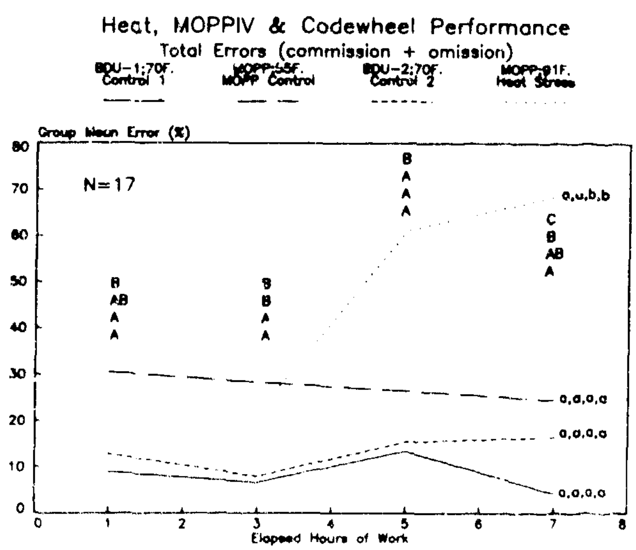

Figure 2a

Figures 2b and 2c indicate that virtually all of the increase in percent group error shown in Figure 2a in the MOPP-Heat-Stress condition was due to increases in errors of omission. Small, but statistically significant, increases in errors of commission were noted in the MOPP-Control condition.

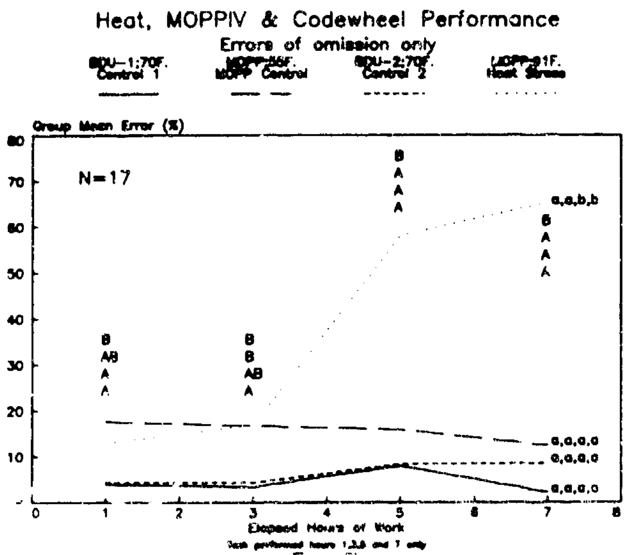

Figure 2b

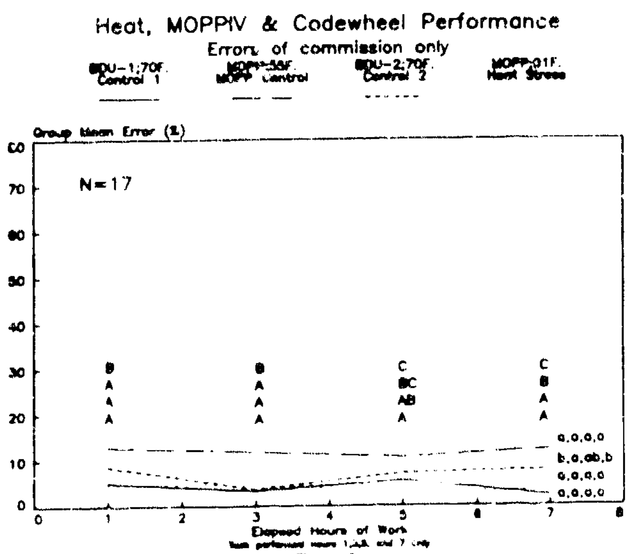

Figure 2c

COMPUTATION OF SITE: Of the three self-paced tasks, computation of Site was the only one in which the messages to the participants were repeated. This accounts for the lower error rate in the control conditions as seen in Figures 3a, 3b, and 3c.

An ANOVA of the total (omission plus commission) group mean errors (Figure 3a) resulted in a significant effect for Conditions ($F=45.12$; df 3,256; $P<.00001$) and for Elapsed Hours of Work ($F= 9.99$; df 3,256; $P<.00001$) and a significant Conditions by Hours interaction ($F=10.23$; df 9,256; $P<.00001$).

The two BDU-Control conditions were exceptionally stable over time; BDU-Control-1 varied less than 3% from hour to hour over the seven hours and BDU-Control-2 varied no more than 1.3%. The two conditions also were remarkably similar to one another; the largest difference between them was observed at hours one and three and was only 1.5%. It is obvious that the task was greatly overlearned.

The significant decrement in the MOPP-Control condition observed with the Codebook and Codewheel tasks was not apparent here. No significant differences were found between the MOPP-Control condition and the two BDU controls at any hour. This may be due to the fact that the Site messages were repeated, leading to a lower error rate.

With regard to the effect of heat on computation of Site, the MOPP-Heat-Stress condition did not differ from the MOPP control condition in the first or third hours, but in the fifth hour a dramatic increase in error rate to 54.1% occurred. Again, this increase was due to a number of participants being evacuated from the chamber. The average error increased to 62.6% by the seventh hour.

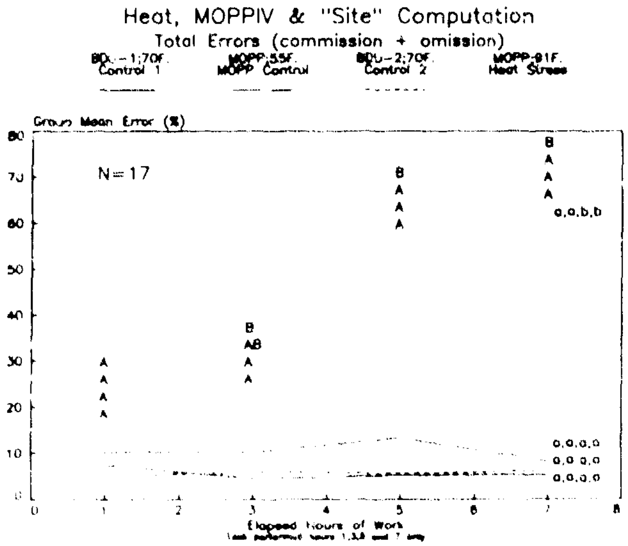

Figure 3a

Figures 3b and 3c show that the major effect was due to increases in errors of omission, although relatively small but significant increases in errors of commission did occur in hours 3 and 5.

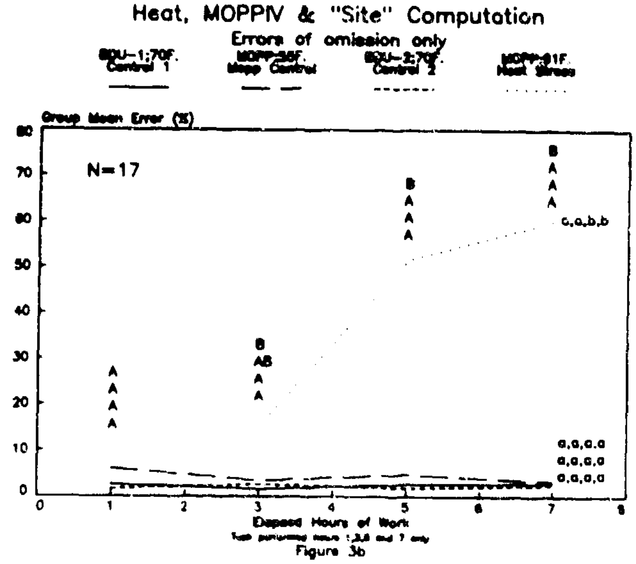

Figure 3b

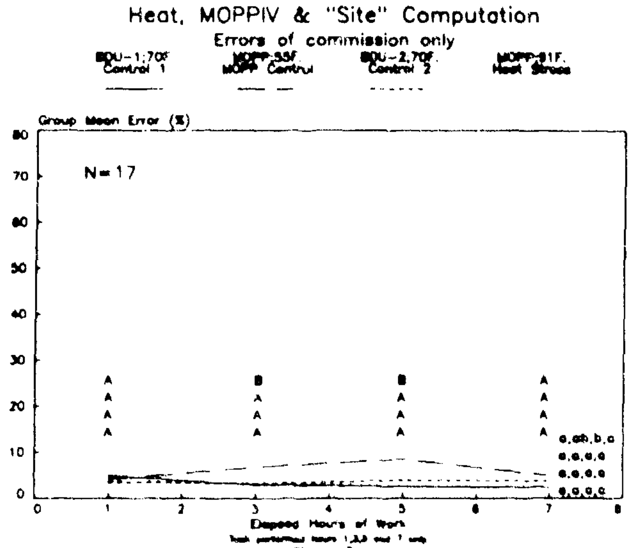

Figure 3c

MAP PLOTTING: This task is separated into two categories: performance concurrent with the radio-message reception tasks ("partially self-paced;" hours 1,3,5 and 7) and performance unaccompanied by those tasks ("totally self-paced;" hours 2,4, and 6).

During hours 1,3,5 and 7, the frequency and duration of incoming radio messages were not controllable by the participants. While they could reduce their plotting productivity, they could not increase it beyond the time constraints imposed by the incoming messages. Typically, fewer targets were plotted during these hours because of the interference of the radio-messages with the plotting process.

During hours 2,4, and 6, each person had a 30-minute period available exclusively for working on maps at their own pace with no interference of any kind.

NUMBER OF TARGETS PLOTTED, HOURS 1,3,5 and 7: The mean number of targets plotted by Conditions and Elapsed Hours of Work is shown in Figure 4a. An ANOVA yielded significant main effects for Conditions ($F=59.5$; df 3,256; $P<.00001$) and for Elapsed Hours of Work ($F= 3.98$; df 3,256; $P<.01$). There was a tendency for more targets to be plotted in BDU-Control-2 than in BDU-Control-1 for hours 1 and 3. The difference was significant only for the third hour. Performance in each of the two BDU-Control conditions was very consistent, testifying to the efficacy of the training.

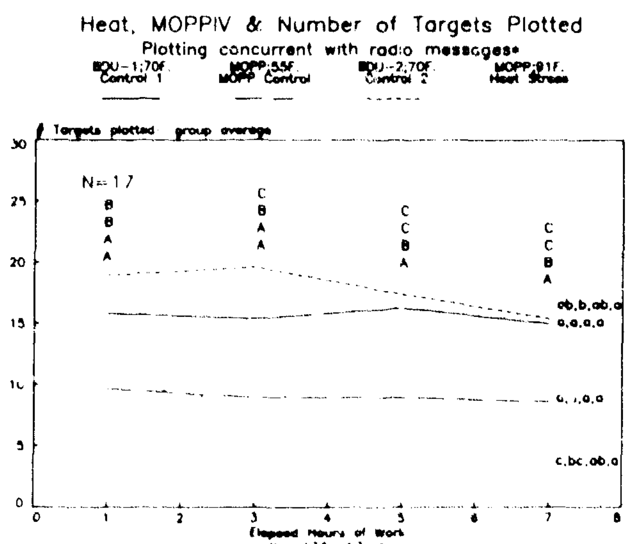

Figure 4a

Significantly fewer targets were plotted in the MOPP conditions than in either of the BDU-Control conditions. In the MOPP-Control condition, simply wearing the protective suit, without the added stress of heat, apparently interfered with performance. However, even with the greatly reduced performance in the MOPP-Control condition, output was very consistent from hour to hour (9.65, 8.94, 8.94 and 8.59 average targets plotted per person per hour for hours 1,3,5 and 7 respectively).

The MOPP-Control and MOPP-Heat-Stress conditions did not differ from one another in hours 1 and 3, but by hour 5, as casualties started to occur, large and significant decrements due to heat became apparent, increasing in the seventh hour.

NUMBER OF TARGETS PLOTTED, HOURS 2,4 and 6: The data for number of targets plotted during hours 2,4 and 6 is presented in Figure 4b. An ANOVA resulted in a highly significant Conditions effect ($F = 36.71$; df 3,192; $P < .00001$) and a significant Elapsed Hours of Work effect ($F = 3.78$; df 2, 192; $P = .02$). As a group, participants performed approximately the same in each of the two BDU-Control conditions; the average number of plots per person ranged from 21.76 to 25.47.

As with the other tasks, performance in the MOPP-Control condition was significantly poorer than in either BDU-Control at each of hours 2, 4 and 6. Average scores for hours 2,4, and 6 were not significantly different from one another, however.

Performance in the MOPP-Heat-Stress condition was significantly poorer than either BDU-Control condition at each of hours 2,4 and 6. Performance in the heat did not differ from MOPP-Control at hour 2, but declined rapidly and signficantly at hour 4 and even further at hour 6, again reflecting the evacuation of stressed persons from the chamber.

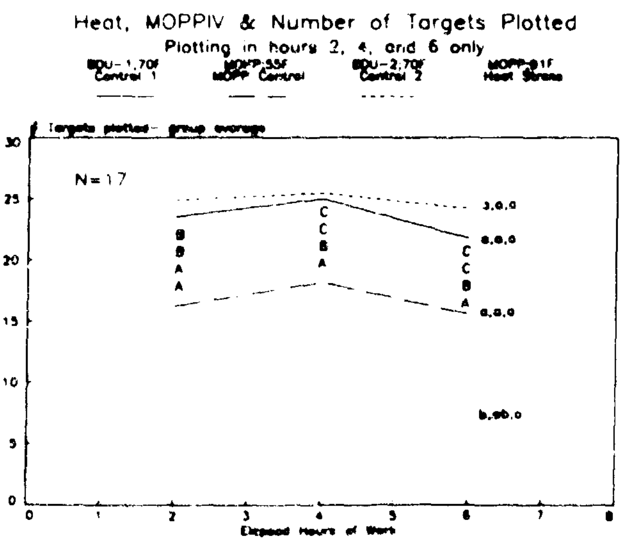

Figure 4b

RANGE, DEFLECTION AND PLOTTING ERRORS: As was the case in the Fine & Kobrick study (5), the training was so effective that very few errors were made in plotting targets or determining range and deflection. Range errors averaged .22 per hour per participant over the entire study. Deflection errors averaged .41 per hour per participant. Plotting errors averaged .78 per hour per participant.

Because of the extremely low incidence of errors, no statistical analyses were undertaken.

Observations

Fine & Kobrick (5) observed that many of their male participants had sweated through at least part of the protective clothing. This was not true among the females in this study, and is consistent with other information that indicates that females sweat less than males at a given temperature (15). While differences in core temperature were not found between the male and female groups, it is possible that the differential survival rates between genders, at least in part, are due to increased evaporative cooling of many of the males, because of wet clothing, even with minimal wind (2.5 mph). Inadequate information is available for a more detailed analysis of the thermal state of the subjects in either study.

Both the demands of the map plotting task, in particular (performed while standing and bending over a plotting board), and the weight of the protective clothing and mask appeared to place rather severe muscular stresses on the women. A common complaint among them was fatigue and even pain in the upper back and neck areas, especially when dressed in MOPP IV. Very few complaints of this nature had been voiced by the male soldiers in the Fine & Kobrick study.

Finally, fitting the masks to some of the smaller women posed some difficulties. Even with the smallest masks available, women with small, narrow faces and high cheek bones often had difficulty in getting the mask to seal properly. Carter and Cammermeyer (4) have noted similar problems with the fitting of face masks to women.

Discussion

In their research on male soldiers, Fine & Kobrick (5) found that the combination of heat and MOPP IV led to a progressive deterioration in group performance (increased errors or decreased productivity, depending on task) starting after about four hours of sustained work. In that study, 18 of 20 persons were able to complete the entire seven-hour exposure. In the present study, deterioration in the women's performance became evident at approximately the same time as the men's, but manifested itself much more drastically; significant numbers of participants began to drop out along the way. In all only 7 of 17 women were able to complete the entire exposure. Since we have noted that most of the women who had to be evacuated were performing quite well up until the time of evacuation, it is probably more appropriate in this study to refer to women's ability to sustain performance, rather than to the effect of the environmental stress on their mental performance. The question becomes one of why males were able to "go all the way," albeit with deterioration in mental performance, whereas females, for the most part, more rapidly reached their limits of endurance, though showing relatively little deterioration in performance at the time of reaching that point?

No answers are available from the two studies in question, but it is clear that future research must address itself to whether there are basic constitutional, physiological or psychological differences between genders which enable males, in general, to more effectively withstand severe stressors or whether the differences found between the two studies specifically were due to sample differences in factors such as states of physical fitness, physical size, motivation, etc.

While both groups performed more poorly in the MOPP-Control condition than in the BDU-Control conditions, women were more severely affected than men. Whereas the men, as a group, had recovered by the seventh hour to where their performance was not significantly different from BDU-Control, the group of women did not show that recovery.

How to account for the difference? First of all, it is not likely that the poorer performance of both groups in the MOPP-Control condition was caused by factors such as impeded manual dexterity due to wearing gloves or to impaired vision because of the mask (13). Everyone had trained about eight hours with mask and/or gloves prior to the MOPP-Control session and no difficulties in writing or manipulating the tools required for the various tasks had been observed. Furthermore, the increase in errors in the MOPP-Control condition primarily was due to increases in errors of omission...to not receiving messages properly, for example, rather than to errors of commission, i.e., faulty writing or tool manipulation.

We speculate that despite training in MOPP IV during the training weeks, the anticipation of wearing the protective suit in the more realistic situation of the experimental week, in a climatic chamber, with the knowledge that seven hours of endurance was expected, aroused some anxiety and imposed its own stress on the subjects. Possibly because of the same factors that were involved in their greater tolerance of the heat stress, males were able to adapt to this first MOPP gear usage after 5-6 hours, whereas females had a tougher time of it. It is informative to note that for all tasks, for both genders, performance in MOPP IV on day 4 (MOPP-Heat-Stress) began at precisely the same mean level that each group had reached at the end of 7 hours on Day 2 in MOPP IV (MOPP Control). This gives credence to the concept of there being an adaptation period in wearing the MOPP gear; it takes a while to get used to it. The adaptation, apparently, was more difficult, in general, for women than for men.

Conclusions

If these results can be generalized, very serious impairments in the ability to sustain performance of cognitive tasks may occur among female personnel wearing chemical protective clothing in the heat; the "unit" represented by the 17 enlisted women in this study was decimated by more than 50% casualties prior to six hours of heat exposure. Additional research is needed to determine whether the gender differences observed reflect basic physical, physiological or psychological differences or reside in transient factors particular to the samples involved, such as differences in physical fitness, size or experience.

In addition, the performance of a majority of the participants was adversely affected by wearing the MOPP gear at 55° F. (MOPP-Control condition), despite having undergone eight hours of practice on the tasks while wearing the gear at that temperature. This effect is similar to, but more severe than, that found with male soldiers. Reasons for this adverse effect are unclear, but do not appear to be due to interference of the gloves and/or mask with dexterity or vision. Adaptation to the novel experimental situation is posited as possibly accounting for the initial decremental effect of wearing the protective gear. This implies that not only is training to do one's job in MOPP IV necessary, but that training under the most realistic situations possible might be considered as a requirement for preparing personnel for the ultimate use of the protective system.

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